

Anatomy of a Bloom: *Heterosigma carterae* in Puget Sound 1997

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Introduction

A massive bloom, of the alga *Heterosigma carterae*, occurred in the main basin of Puget Sound during mid-July 1997. This bloom was responsible for finfish losses in both commercial and research net-pens. Although commercial fish mortalities resulting directly from the alga were low (~4%), total financial losses reached nearly \$2.5 million because of towing associated costs. Currently, towing pens to safer waters is the most frequently used method of risk management in Puget Sound. This involves many hours of preparation and remains a costly form of minimizing losses from these potentially toxic blooms. In order to identify factors that may predict bloom conditions, thus giving advance warning, we have instituted a long-term ecological study in a location that has had finfish mortalities resulting from *H. carterae* blooms in the recent past.

Background

H. carterae is a bi-flagellated, unicellular golden-brown microalga, about 10-20µm in diameter. This alga can be somewhat pleomorphic (it can have varied shapes) (Hara and Chihara 1987). Because of its ability to swim, *H. carterae* is very competitive in stratified waters, where it gleans nutrients from below the pycnocline at night and harvests light for photosynthesis in the upper layers during the day (Watanabe et al. 1983).

World-wide distribution of this raphidophytic alga is restricted to euryhaline coastal waters (Honjo 1992) where *H. carterae* has been associated with net-penned fish deaths primarily in the Pacific (Honjo 1992). Its appearance in the northeast Pacific has been reported since Strait of Georgia monitoring began in 1967 (Taylor and Haigh 1991) and the first reported finfish deaths were in tribal owned ponds off Lummi Island in 1976 (Jefferson 1976; Gaines and Taylor 1986). Conditions leading to blooms of *H. carterae* can be predicted in some areas. The Inland Seas of Japan have numerous blooms beginning in early spring and lasting into late fall (Honjo 1992). These events have been closely attributed to eutrophication and high nutrient supply (Honjo 1992). Extensive studies in Narragansett Bay, RI, found bi-annual blooms in May-June and October (Tomas 1980) where water temperature and salinity were critical, but eutrophication was not a factor. Closer to this area, workers in British Columbia have been able to predict blooms in areas affected by the Fraser River plume by monitoring temperature and salinity (Taylor and Haigh 1991). Occurrence of annual *H. carterae* blooms in the Strait of Georgia coincide with a water temperature in excess of 15 °C and salinity of 15 ppt (Taylor and Haigh 1991). Typically *H. carterae* blooms are first observed during the end of May, soon after these environmental conditions are observed, and blooms can last as long as stable water stratification remains, often until September.

Blooms of *H. carterae* in Puget Sound are infrequent, the last large main basin bloom occurred in July 1990, and caused significant salmon mortalities in both commercial and research facilities (Harrel 1990). Small blooms have been reported near Port Orchard in 1993 (Rensel 1995), one near Case Inlet (south Puget Sound), which caused fish losses in September 1994 (Hershberger et al. 1997), and several small sustained blooms along the west side of Bainbridge Island, near Brownsville, WA, and in Liberty Bay (Bernier 1996).

Clam Bay 1995-1997

Less frequent occurrence of *H. carterae* blooms in main basin Puget Sound pose a prediction

challenge to growers and researchers alike. To determine which factors can be used as early warning predictors of these blooms in Puget Sound, we instituted a long-term ecological study in Clam Bay, located within Rich Passage. This site was selected because it has both commercial and research salmon pens that were severely impacted during the 1990 bloom (Harrel 1990), easy access without a boat, and suitable sites for semi-permanent equipment deployment. A set of physical and biotic indicators was monitored on a weekly basis between July 1995 and August 1997 (Table 1).

Table 1. Parameters monitored in Clam Bay, WA July 1995-August 1997.

Incident Light	Water Temperature (datalogger)
Dissolved Organic Carbon (DOC)	Air Temperature
Nitrogen Panel (NO ₂ ; NO ₃ ; NH ₄)	Phosphate
Conductivity (converted to salinity ppt)	Dissolved Oxygen
Secchi	Silica
Total Bacteria	Species Composition
Chlorophyll	pH

No *H. carterae* bloom was reported in Clam Bay during 1995 or 1996; however, on 14 July 1997, aerial surveys located several small blooms off of the east side of Bainbridge Island. The water was quickly covered with rusty-brown streaks of *H. carterae* cells. These blooms spread rapidly, carried by currents and tide, until it eventually covered >3000 km² (18 July). As rapidly as the bloom spread, it began to disintegrate, aggregations of dead cells were seen floating in the main basin on 21 July and by 29 July only fragments of the bloom remained in shallow embayments. In Clam Bay, the highest cell densities were routinely found at 2-m depth, reaching a maximum of 7.93 million cells L⁻¹ on 18 July. Because of the herding and diurnal vertical migration phenomena observed in these blooms (Wada et al. 1985), exact cell numbers are difficult to obtain. Samples taken at the surface, when the bloom was beginning to disintegrate and cells were sticking together in mats, had higher counts (up to 42.48 million cells L⁻¹). The cell morphology of this alga changed throughout the bloom with the typical "potato" shaped cells observed during the early days, progressing to a "potato chip" shape by 22 July and with the first cyst, or non-motile round cells, observed on 23 July.

Net-pen finfish impact varied by species and pen location (Table 2). Most fish mortalities at the NMFS pier in Clam Bay occurred early in the bloom, on or before 17 July. Global Aqua sustained significant losses attributed to towing, rather than directly from *H. carterae* mediated mortalities. Similar mortalities were observed between pens towed from Rich Passage and those which remained in Clam Bay (~4%).

Table 2. Fish mortality by species from net-pens in Clam Bay WA, July 1997.

Owner	Species	% Mortality	Number
NMFS	Chinook	~10	407
NMFS	Coho	100	326
NMFS	Sockeye	<.1	4
Global Aqua	Atlantic	~4	200
Global Aqua*	Atlantic	~4	28,552

* Pens towed from Rich Passage into Colvos Passage and east of Vashon Island, Puget Sound.

Nutrient inputs from the Fraser River have been postulated to be underlying stimulation for extended *H. carterae* blooms in Sechart inlet (Taylor et al. 1994). To explore nutrients as stimulating factors in *H. carterae* blooms in Puget Sound we sampled on a weekly basis in Clam Bay. The nutrient (nitrogen and phosphate) profile among the seasons was very similar, except after the 1997 *H. carterae* bloom reached Clam Bay (16 July). Nitrate levels dropped to 1.42 µM and slowly rose back to normal summer levels (~14 µM) within 5 days (Figure 1). This decrease in nitrate levels is most likely a consequence of the *H. carterae* bloom and not a factor involved in bloom initiation, thus nutrients were not useful as a predictive indicator.

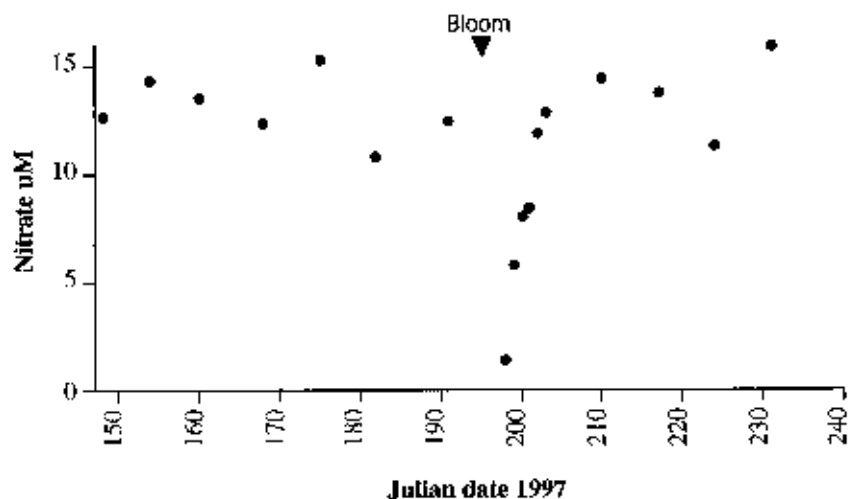


Figure 1. Nitrate levels in Clam Bay, WA from July 1997. The *H. carterae* bloom is indicated by an arrow.

As in areas impacted by Fraser River plume, both temperature and salinity were the parameters that displayed the most striking correlation with this *H. carterae* bloom. Water temperatures at 1 m were significantly higher in 1997 as compared with the previous years (Figure 2). The maximum water temperature recorded during 1995 and 1996 was 13.8 °C. Temperature spikes began in early 1997 gradually rising as the season progressed. These temperature spikes were associated with neap tides and reached a peak of close to 17 °C. This 1997 *H. carterae* bloom did not occur until after the water temperature rose above 16 °C, close the 15 °C target for Fraser River delta monitoring program.

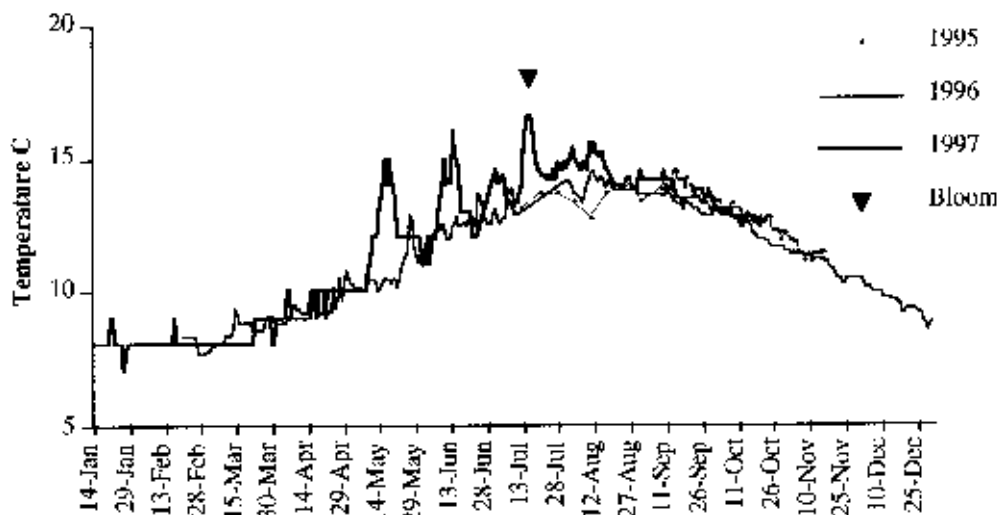


Figure 2. Surface water temperature (1 m) in Clam Bay, WA 1995–1997. Bloom is indicated by an arrow.

Shallow water column stratification (both temperature and salinity) was observed only during the early periods of this bloom and at no other time during the project (Figure 3). Typical surface (1 m) salinity during previous summers was between 21 and 22 ppt. During the 1997 *H. carterae* bloom, salinity (1 m) dropped to 19.4 ppt, and did not approach the 15 ppt target for the Fraser River monitoring program. Although the gradient from surface to bottom was small for both salinity and

temperature, a shallow stratification was able to develop by mid-July during the bloom, and subsequently broke down rapidly by 21 July.

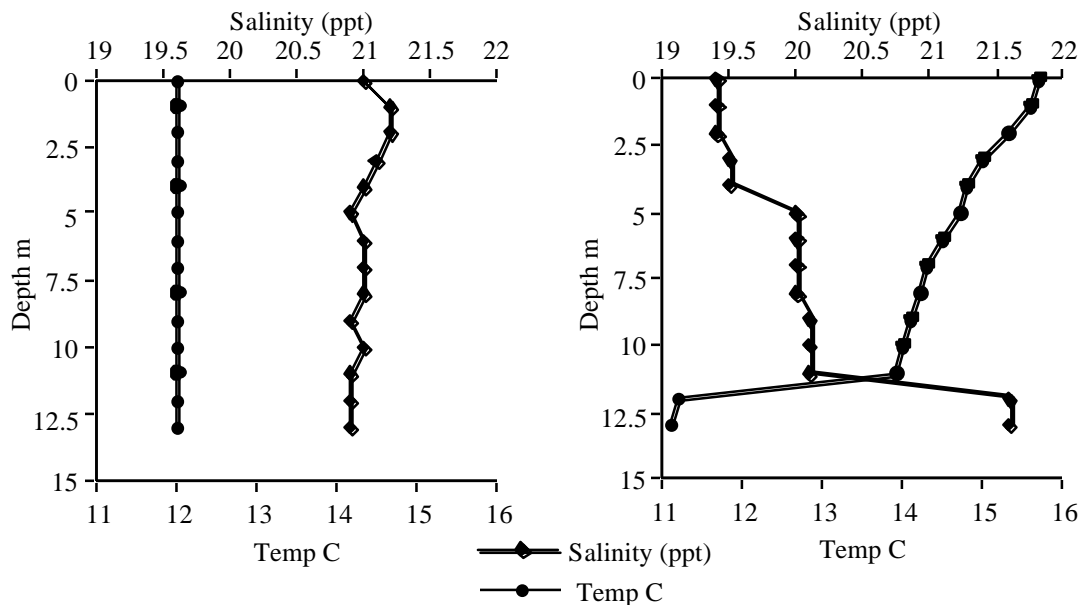


Figure 3. Shallow stratification in Clam Bay, WA. Temperature and salinity profile from (a) typical summer—17 June 1996 and (b) bloom—17 July 1997.

Conclusions

Puget Sound blooms of *H. carterae* occur somewhat later in the season than those in Japan, Fraser River delta and Narragansett Bay (July rather than May). This organism bloomed when the water temperature reached ~16 °C and the salinity dropped to ~19 ppt again, somewhat different from the 15°C/ 15 ppt target for the Fraser River area. The exact temperature and salinity may not be as critical as the development of shallow stratification (5 to 11 m). Stratification in Puget Sound is transitory; this 1997 episode was very short-lived, disintegrating within days. We found that the water temperature profile during 1997 was very different from past years. The source of this warmer water has yet to be identified. In summer, the average epilimnion temperature of Puget Sound is somewhat colder than the Fraser River delta, Inland Seas of Japan and Narragansett Bay, and it does not generally maintain stratification during summer months. Therefore, Puget Sound may be less likely to exhibit major *H. carterae* blooms than areas that have warmer water and can maintain stratification. Colvos Passage, on the west side of Vashon Island, has a net northward circulation fed through south Puget Sound during all tidal cycles and remained clear of *H. carterae* during 1997. This makes it an attractive refuge for towed net-pens provided the bloom remains excluded from south Puget Sound.

Although massive, this bloom was not as lethal as the one in 1990. Finfish mortalities in 1997 were light (~ 4%), in comparison with 1990, where many pens experienced 100% mortality (Harrel 1990). The major damage during the 1997 bloom was the loss of fish from research projects and costs attributed to commercial pen towing.

Determining environmental indicators for early warning of potential blooms is an important goal. Increased local rainfall (51% above average) during the month of June 1990 was hypothesized as a contributing factor in the 1990 *H. carterae* bloom (Rensel 1995). Rainfall patterns in May, Jun, and July for 1995–1997 (NOAA regional data center) did not show a pattern correlating with salinity drops at Clam Bay (data not shown). Therefore, it is unlikely that local rainfall had a significant impact on the pycnocline development observed in Clam Bay during July 1997.

Surface water from Admiralty Inlet has been suggested as a potential early warning monitoring tool, because that site was warmer (15 °C) and less salty (19 ppt) than usual 10 days before the 1990 *H. carterae* bloom (Rensel 1995). Dense, cold, saline ocean water flows into Puget Sound at depth and warmer, less salty water exits primarily on the surface (Ebbesmeyer and Barnes 1980). Therefore, monitoring surface water in Admiralty Inlet will give useful information for the early “hind-casting” steps in model generation but will not be an effective bloom early warning indicator. Further research, to determine the environmental factors that produce warmer and stratified surface waters, is critical for understanding bloom initiation events. These data, combined with information accumulated from long term studies sites around Puget Sound, such as this one, may provide suitable starting points for numerical models, leading to determination of early warning parameters.

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